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Forest Pest Control-Technical Report 1

Conifer Damage and Death Associated with the Use of Highway Deicing Salt in the Lake Tahoe Basin of California and Nevada

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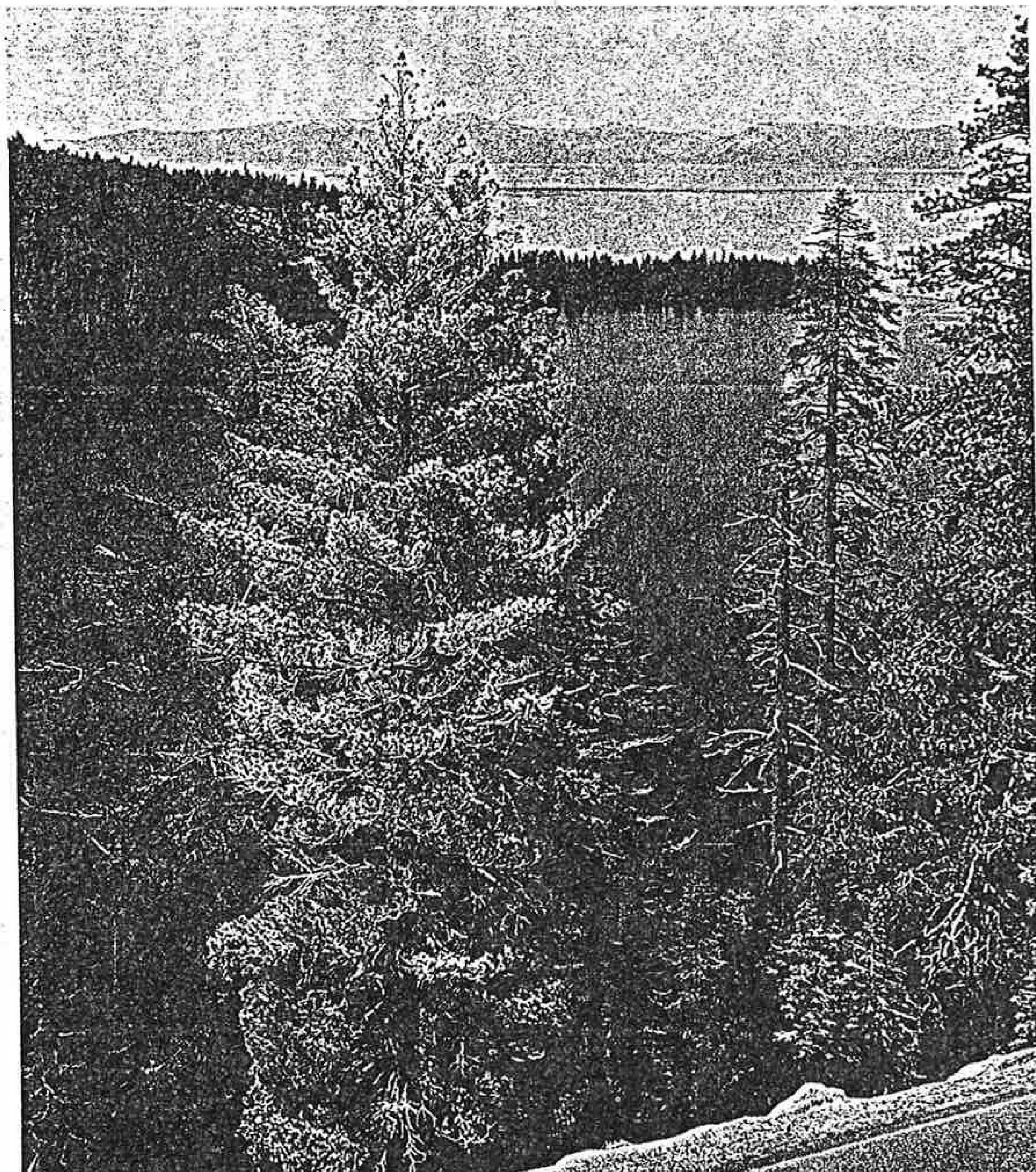

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COVER PHOTO: The needles of this dying, salt-damaged sugar pine appear pale in comparison to the darker foliage of nearby, healthy trees. Most of the crown of this pine is severely affected by the uptake of salt used for highway deicing; the lower portion of the crown is damaged also, although it retains a darker, healthier appearance.

This sugar pine is located downslope from Highway 89 above Emerald Bay, on the west shore of Lake Tahoe. (Forest Service photo by Vincent Piantanida.)

CONIFER DAMAGE AND DEATH ASSOCIATED WITH THE USE OF HIGHWAY DEICING SALT IN THE LAKE TAHOE BASIN OF CALIFORNIA AND NEVADA

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SUMMARY

In the winter of 1972-73 severe damage to conifers was observed along the major state and county highways in the Lake Tahoe Basin. Local foresters suspected highway deicing salt as the cause of damage.

In response to a request from local Forest Service officials, the authors began a biological evaluation in the spring of 1973 to determine the cause and distribution of damage to the roadside conifers, the species affected, and the relationship of tree damage to the distances of trees from the highways. Greenhouse tests were conducted to determine if symptoms and damage produced under controlled conditions duplicated those observed in the field.

Estimates from the evaluation indicate that some 3000 trees died or were damaged on more than 300 locations in the Basin. Browning of foliage, branch dieback, and in many cases, dead trees of all sizes and ages were observed. Damage and death were greater for trees near highways and less for trees at greater distances from the highways; in some cases damage occurred up to 60 feet from the pavement. Concentrations of sodium and chloride were several times greater in trees near highways than in trees not exposed to salt. The concentrations of these ions in foliage tissue were directly related to damage symptoms. Tests in the greenhouse, which involved adding different concentrations of salt solution to potted trees, duplicated symptoms and damage observed in the field.

It was concluded that salt applied to the highways is a major cause of damage and death to roadside conifers in the Basin. Damage probably will continue to occur if the use of sodium chloride for highway deicing continues at the present level.

NOTE. The California Department of Transportation is conducting a comprehensive environmental analysis of the use of deicing salt in the Tahoe Basin with the goal of developing alternate deicing methods. These studies are being made with the cooperation of the University of California, Davis, and Ecological Research Associates. The interrelationships of salt application rates, drainage patterns, salt tolerance, soil properties, and snow removal practices are being reviewed.

CONTENTS

INTRODUCTION 1

SCOPE AND OBJECTIVES 2

METHODS 3

Detection and Incidence Survey
Temporary Field Plots
Greenhouse Tests

RESULTS 7

Detection and Incidence Survey
Temporary Field Plots
Greenhouse Tests

CONCLUSIONS 14

RECOMMENDATIONS 15

LITERATURE CITED 16

INTRODUCTION

In 1968 a report by the California Region of the Forest Service and the Pacific Southwest Forest and Range Experiment Station directed that these organizations "develop a system for identifying and measuring environmental contaminants affecting vegetative growth in the forests of California. A program to reduce or eliminate those soil and water contaminants which are found to be intolerable should be initiated promptly." The report identified highway deicing salt as a possible pollutant.

In the winter of 1972-73 severe damage to conifers was observed along the major state and county highways in the Lake Tahoe Basin. The symptoms and the proximity of damaged trees to roads indicated that highway deicing salt (sodium chloride) might be the cause of damage.

Damage to vegetation by salt has been recognized for some time (Bernstein, 1964; Anonymous, 1965; Westing, 1969; Hanes, et al, 1970; U. S. Salinity Laboratory Staff, 1954, 1973; and McConnell and Lewis, 1972). Most of the available information, however, applies to agricultural damage or to tree damage in the Eastern United States and in Europe. Little information is available on the effects of salt on the forests of the West.

Therefore, in the spring of 1973 the Pacific Southwest Forest and Range Experiment Station and the California Region undertook a cooperative study to determine if highway deicing salts were damaging and killing the roadside conifers in the Lake Tahoe Basin. The following is a report of that biological evaluation. Studies dealing with the long-term effects of salt on conifers and portions of the greenhouse tests are continuing; those results will be included in an addendum to be issued in 1979.

SCOPE AND OBJECTIVES

The evaluation was limited to determining if highway deicing salt was damaging and killing conifers along the major state and county roads in the Lake Tahoe Basin.

The objectives of the study were four:

- To determine the distribution of dead and damaged roadside conifers within the Basin.
- To determine the relationship between the concentrations of sodium and chloride in foliage tissues and the damage ratings.
- To determine if there was a relationship between conifer damage and the proximity of trees to salted highways.
- To determine if highway deicing salt was a major cause of damage and death.

To accomplish these objectives the study was conducted in three phases:

- Detection and Incidence Survey — To determine the distribution of damage to the major roadside conifers in the Basin, describe the symptoms, and rate the damage to selected trees.
- Temporary Field Plots — To determine the species affected, the relationship of tree damage to the distances of trees from the highways, and the effects of topographical factors on the extent of damage.
- Greenhouse Tests — To determine if symptoms and damage produced under controlled conditions duplicated those observed in the field.

Laboratory analyses were conducted in each phase to determine the relationships of the levels of sodium and chloride in conifer tissues to symptoms and damage.

METHODS

DETECTION AND INCIDENCE SURVEY

In April 1973 a survey was made along all the major state and county highways in the Lake Tahoe Basin to determine the extent and severity of salt damage to conifers. All trees or groups of trees growing within 200 feet of highways and appearing to have been damaged by salt were recorded and plotted on a map.

The symptoms of salt damage to certain conifers have been described by other observers (Monk and Peterson, 1962; Spotts, et al, 1972; Strong, 1944). These descriptions fitted the symptoms observed on some of the species in the Lake Tahoe Basin, particularly the pines. For firs and incense-cedars, however, symptoms had not been described previously.

To confirm that the diagnostic symptoms used to identify salt-damaged trees were accurate, foliage samples exhibiting the symptoms described below were collected from the crowns of 53 individual coniferous trees of different species and sent to the laboratory for analysis. The following data were recorded for each tree: species, d.b.h., damage rating, distance from the highway, and location. All trees sampled were within 100 feet of deiced highways. As a control, in nearby sites not exposed to deicing salts foliage samples were collected from three trees of each study species: Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), sugar pine (*Pinus lambertiana* Dougl.), white fir (*Abies concolor* (Gord. & Glend.) Lindl.), and incense-cedar (*Libocedrus decurrens* Torr.).

The salt damage ratings used in all studies were based on the following criteria:

No Damage	—	No tipburn or needle browning. Chlorotic trees were included in this rating until further symptoms developed.
Light Damage	—	Damage to one-third or less of the foliage, with only the very tips of the needles showing tipburn.
Moderate Damage	—	One-third to two-thirds of the foliage damaged, and one-half or less of the length of the damaged needles on pines showing tipburn.
Severe Damage	—	Two-thirds or more of the foliage damaged, and on pines 50 percent or more of the needle length showing tipburn. Trees completely brown and apparently dead were included in this category.

LABORATORY ANALYSIS

Excessive accumulations of sodium and chloride ions are toxic to many plants (U. S.

Salinity Lab, 1954). Conifers in general are considered salt intolerant (Monk and Peterson, 1962); in Colorado, ponderosa pines are known to suffer severe damage from increased levels of chloride alone (Spotts, et al, 1972).

The concentrations of specific ions in plant tissues can be readily determined by chemical analysis. This method was used to relate symptoms and damage observed in the field with the levels of sodium and chloride in the conifer foliage.

Analyses were made on samples of damaged foliage from two main branches of each tree exhibiting salt damage symptoms. Foliage was collected also from the main branches of trees not showing symptoms or damage. Samples from each tree were placed in a paper bag and dried in a forced air oven at 60°C for 12 hours. The dried foliar tissue was then ground to pass through a 40-mesh screen, placed in a screw cap vial, and submitted for sodium and chloride analyses to the Agricultural Research Service, Western Regional Research Center.

SYMPTOMS

The following are descriptions of the symptoms of salt damage on the major conifers in the Lake Tahoe Basin.

The Pines. Symptoms were essentially the same for all pine species observed (Jeffrey pine, lodgepole pine, and sugar pine). Tip dieback (or tip burning) of the youngest foliage is the most conspicuous and distinctive symptom of salt damage. The precise time of year when this dieback begins on new foliage is not known; however, the current year's foliage may show conspicuous dieback before the buds break in the spring. Dieback progresses with time, and is uniform along all the needles on a single branch. The margin between dead and living tissue is very distinct, resulting in branches and trees that exhibit a "halo" of dead foliage tips when the damaged branches are observed frontally. Needle banding, as described by Spotts, et al (1972), was observed also on the brown portions of damaged needles in late summer and fall. One to several dark bands were often found on the dead portions of needles.

Salt damage may be scattered or continuous throughout a tree. Many trees of all sizes showed symptoms throughout the crown; in other cases the tops or the lower portions of the crowns were affected. The reasons for differences in the extent of damage and in the locations of symptom development are not fully understood; these differences are probably associated with the pattern and extent of salt uptake by the root system, as well as by absorption of salts through foliar contact.

The advanced symptoms of salt damage may be a complete browning of the foliage, and subsequent death of the tree. Field diagnosis of salt damage at this stage is questionable and the symptoms may be confused with other causes of tree death. Laboratory diagnosis is needed to confirm salt damage at this stage.

White Fir. Tip dieback of the needles of white fir is the primary symptom of salt damage. Because the needles are short and oriented on the branches in a nearly flat plane, and because they normally persist and function on branches for many years, the circular "halo" effect of damaged foliage was not observed on firs as it was on pines. From a distance, salt-damaged firs showed various degrees of foliar browning.

Firs, more than any of the other species observed, exhibited an irregular pattern of damage within the crown. Some trees were damaged throughout the crown, some had top damage, others showed lower crown damage, and others showed only scattered crown damage. One variation in the type of damage to firs was vividly illustrated by several trees which had a definite spiral pattern of damage. The most plausible explanation for this pattern is that damaging levels of salt were taken up through one portion of the root system only and translocated upward through the trunk in a spiral manner, causing foliar damage only to the branches using the water and salts in this translocation stream. A spiral translocation pattern of water uptake in red fir has been reported by Owston, et al (1972). Thus, uptake of salts by portions of a root system and differing translocation patterns within trees may account for scattered and variable patterns of salt damage within the crowns of firs, and possibly of other conifer species.

True firs with advanced symptoms of salt damage have little foliage and thin crowns. Dead trees, or trees with all brown foliage, should be analysed in the laboratory to determine if salt contributed to the death of the tree.

Incense-cedar. Symptoms of salt damage to incense-cedars appeared different from those observed on pines and firs because of the growth characteristics of the foliage. Incense-cedars, unlike pines and firs, have a fan-like pattern of foliage and branch growth, and small, scale-like leaves that are not readily distinguishable from the stem segments. Because of these growth differences, tip dieback of the foliage of incense-cedars is not easily recognized from a distance; rather, damaged trees have sparse foliage and exhibit a brownish cast as a result of extensive foliage dieback. However, close observation often reveals distinct tip dieback.

TEMPORARY FIELD PLOTS

Temporary field plots were established at the Eldorado Beach picnic area in South Lake Tahoe, at Bliss State Park near Emerald Bay, and at Sand Harbor State Park in Nevada. The plots varied in size and shape, but all met the same general criteria: each plot contained 100 trees, 4 inches d.b.h. or larger, and selected at random. All plot trees were marked with a small metal tag nailed to the tree at ground level. Information was collected on the species, d.b.h., salt damage rating, distance from the edge of the highway, and growth rate. Foliage was collected for chemical analysis from every fifth tree on each plot.

GREENHOUSE TESTS

In the spring of 1973 studies were begun to determine the effects of salt on young conifers growing under controlled conditions. Two-year-old seedlings of ponderosa pine (*Pinus ponderosa* Laws.) and incense-cedar were obtained from the California Division of Forestry's Ben Lomond Nursery, planted in 8-inch pots using one-half sand and one-half U.C. mix, and stored for testing at the Pacific Southwest Forest and Range Experiment Station in Berkeley. Three concentrations of salt solution were applied to the test trees; these concentrations were lower than those used by Spotts, et al (1972) for greenhouse tests with ponderosa pine.

Control — Tap Water.
1 ton salt per acre ft. water (700 ppm).
4 tons salt per acre ft. water (2800 ppm).
8 tons salt per acre ft. water (5600 ppm).

Each tree was watered at the soil level with 100 ml. of solution once a week for a period of 20 weeks. Routine watering with plain water was continued during this period also. Thirty trees of each species were treated with each concentration of salt in water, and thirty trees of each species were treated with plain tap water as controls. In all, 240 trees were tested.

The development of symptoms and damage was recorded throughout the 20-week period of the test. Immediately after the end of the 20 weeks, 40 percent of the trees were selected at random for chemical analysis. The remaining trees are being examined periodically for subsequent damage or recovery.

The criteria used to rate salt damage were the same as described previously.

RESULTS

DETECTION AND INCIDENCE SURVEY

The general locations and the extent of tree damage are shown in Figure 1. In all, 321 sites were found to contain one or more trees showing symptoms of salt damage. Although the precise number of trees affected was not determined, estimates indicate that approximately 3000 conifers six feet or taller were dead or damaged. Damaged trees were located on both public and private lands.

Trees of all sizes were affected. Damage was noted on seedlings as well as on trees as large as several feet in diameter, and damage appeared to be as severe on large trees as on small ones.

Along the highways in the Basin all of the major species of conifers were damaged to some extent. Jeffrey pine, incense-cedar, and white fir were the species most commonly damaged, primarily because they are the most abundant in the area. Sugar pine, although less abundant, were severely damaged in certain locations and appeared to be particularly susceptible to damage from salt. Lodgepole pine (*Pinus contorta* Dougl.), were damaged in a few locations and may be less susceptible to salt injury than some of the other conifer species. Western junipers (*Juniperus occidentalis* Hook.) found along the highways did not show damage, but were too few to determine whether they were more resistant to injury or had escaped exposure to salt.

The survey indicated that about three-fourths of the sites where tree damage was noted were on the down-hill slopes from the highways. Of the remaining one-fourth of the sites, most were on the level, while a few were on up-hill slopes. Nearly all tree damage occurred within 60 feet of each side of the highways, with damage most severe close to the highways and less at greater distances from them.

Damage was not uniform along the highways. In some locations, only scattered trees showed damage. In others, groups of trees were damaged, and in some cases nearly all the trees were damaged in a continuous strip of from one to three-tenths of a mile along one or both sides of the highway. Soil drainage patterns, the amounts of salt applied, and the types of snow removal methods used are undoubtedly important factors affecting the irregular occurrence of tree damage.

TEMPORARY FIELD PLOTS

The results presented in this section are based on the analyses of foliage collected as part of the Detection and Incidence Survey and the Temporary Field Plot study.

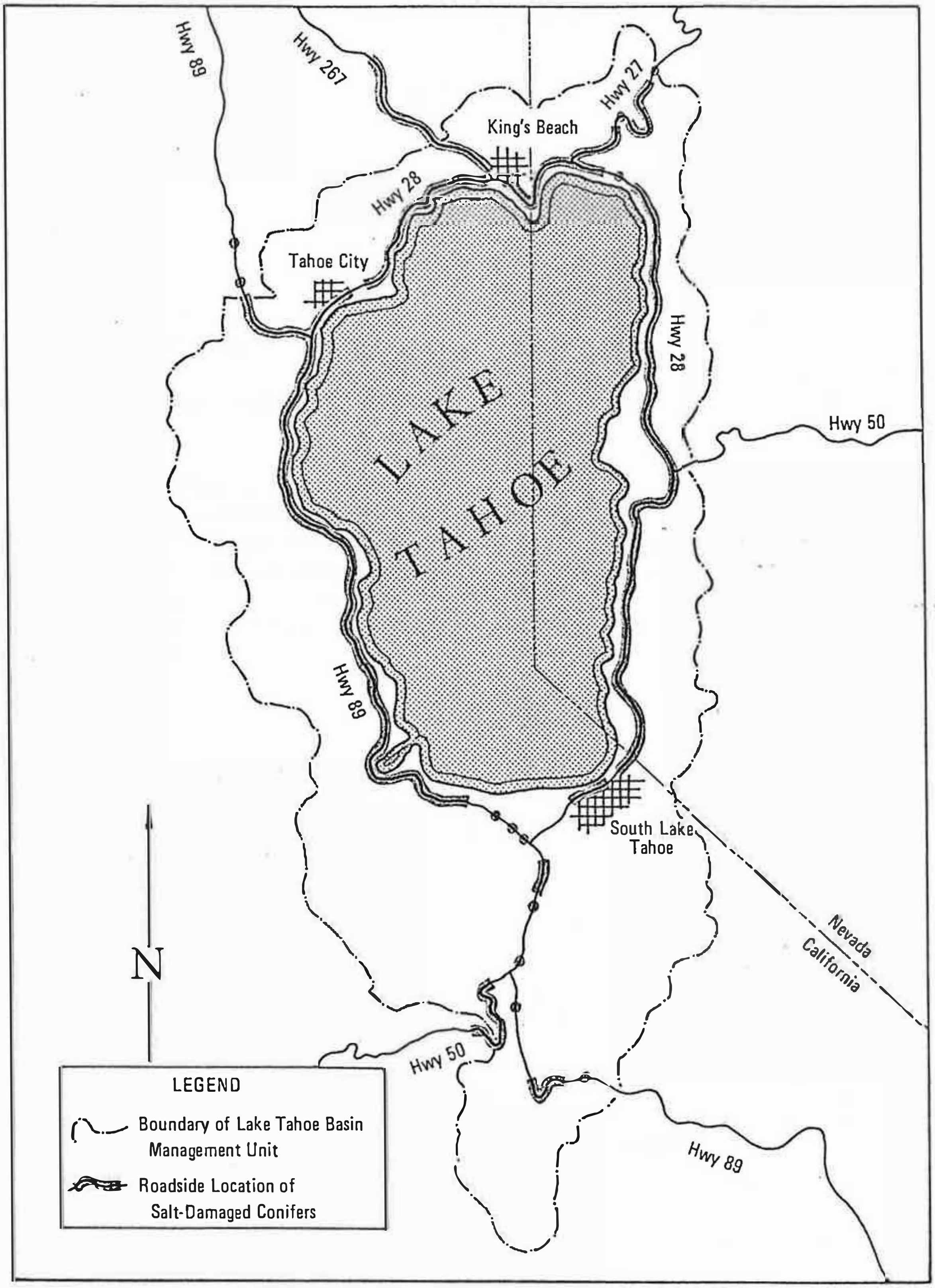

FIGURE 1. The locations of salt-damaged roadside conifers at Lake Tahoe, April 1973.

TREE DAMAGE AND CONCENTRATIONS OF SODIUM AND CHLORIDE IN FOLIAGE TISSUES IN RELATION TO THE DISTANCES OF TREES FROM DEICED HIGHWAYS.

The average distances from the edges of the highways to trees showing different salt damage ratings were the following:

No Damage — 41 feet.
Light Damage — 21 feet.
Moderate Damage — 20 feet.
Severe Damage — 15 feet.

In all three damage categories, however, some trees were found as far as 60 feet from the pavement, and others closer than 10 feet. Of the total number of moderately to severely damaged trees recorded, 75 percent were within 20 feet of the edge of the highway. Only 34 percent of the undamaged and lightly damaged trees in the study were within 20 feet of the edge of the highway.

The concentrations of sodium and chloride in the foliage of conifers were found to be related to the distances that the trees were growing from the edge of the highway (Figure 2). The most striking relationship was found for chloride. At distances up to 20 feet from the highways, the conifers analysed showed mean concentrations of chloride several times greater than the mean concentrations found in trees at greater distances, or in control trees not exposed to deicing salt.

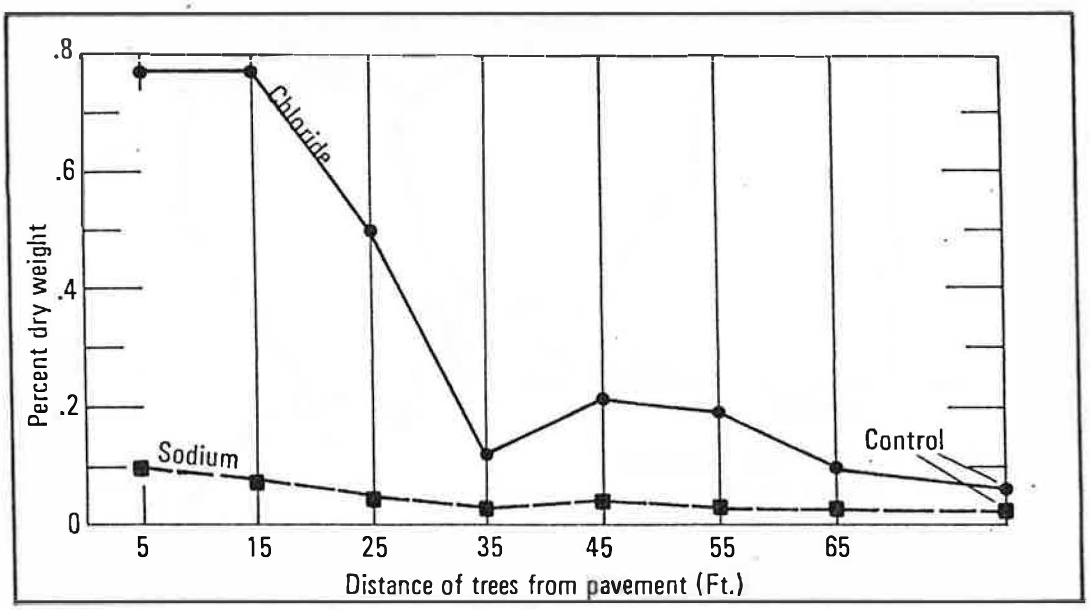

FIGURE 2. The percent dry weight of sodium and chloride in conifer foliage in relation to the distances of the trees from highways deiced with salt.

Even at distances up to 60 feet from the pavement, concentrations of sodium and chloride were higher than in the controls. Thus, increased damage is directly related to increased concentrations of sodium and chloride, and to the proximity of trees to highways deiced with salt.

LEVELS OF SODIUM AND CHLORIDE IN FOLIAGE OF DIFFERENT DAMAGE RATINGS.

The levels of sodium and chloride in the foliage of three major conifers in relation to the salt damage ratings are shown in Table 1.

For the major conifers not exposed to deicing salt (controls), no significant differences were found in the naturally occurring levels of sodium. Naturally occurring levels of chloride in control trees differed somewhat among the three major conifer species; however, these levels were far below the levels of chloride in trees showing damage symptoms. As Table 1 shows, increased tree damage is associated with increases in concentrations of both sodium and chloride.

	DAMAGE RATING	JEFFREY PINE	WHITE FIR	INCENSE-CEDAR
SODIUM	Control	.002 ± .001	.002 ± .001	.001 ± .001
	None	.027 ± .011	.023 ± .016	.014[1]
	Light	.042 ± .011	.022 ± .010	.037 ± .041[2]
	Moderate	.034 ± .007	.036 ± .005[2]	.062 ± .042[2]
	Severe	.077 ± .035	.192 ± .085	.072 ± .044
CHLORIDE	Control	.020 ± .025	.047 ± .062	.097 ± .103
	None	.094 ± .022	.185 ± .073	.330[1]
	Light	.271 ± .081	.302 ± .210	.503 ± .297[2]
	Moderate	.535 ± .131	.853 ± .082[2]	.990 ± .831[2]
	Severe	.855 ± .150	1.204 ± .199	1.387 ± .083

[1]Not enough observations to determine confidence intervals.
[2]Small sample (2-3 observations).

TABLE 1. The means of percent dry weight of sodium and chloride found in the foliage of three major conifers growing beside highways deiced with salt, and the 95 percent confidence intervals around the means.

Among the trees within a given damage rating, some variations were recorded in both sodium and chloride levels, and these variations were present in all damage rating categories. The variations suggest possible differences in salt tolerance among individual trees. Differences in salt tolerance among individual ponderosa pines in Colorado have been reported by Spotts, et al (1972).

GREENHOUSE TESTS

These results are based on observations of the relationships between salt-damaged trees in the greenhouse and trees damaged in the field.

The times required for recognizable symptoms to appear and for damage to occur were similar with ponderosa pines and incense-cedars, even though the pines were grown under artificial light in a temperature-controlled greenhouse, and the cedars were grown out-of-doors in a lath-house in Berkeley. Chlorosis, or yellowing, of the seedling foliage was the first noticeable symptom of damage to most pines and cedars treated with salt; in a few cases tipburn occured before chlorosis. Chlorosis was recognizable on trees treated with 2800 and 5600 ppm salt about two months after the start of the tests.

Tipburn of the new foliage was the first diagnostic symptom of salt damage on both pines and cedars. Tipburn appeared on both species between the second and third months following the start of treatments with 2800 and 5600 ppm salt solution. The time required for symptoms to appear corresponded closely to that found by Spotts, et al (1972) for salt damage to greenhouse-grown ponderosa pines. At 700 ppm salt, tipburn symptoms were not recognizable on either species until the third month after treatment.

Tipburn of pines was limited initially to the new foliage. The tipburn progressed toward the base of the needle fascicle until all the new foliage was dead; only then did older foliage begin to show tipburn. Severely affected trees eventually died.

With pines, the margins between the dead and live portions of the needles were distinct, and dark banding occurred on some. Needle banding was observed also on salt-damaged ponderosa pines in the field, and by Spotts, et al (1972) on salt-damaged ponderosa pines grown in the greenhouse. Pine seedlings tended to die from the tops down, probably because much of the new foliage is in the terminal bud. Incense-cedar seedlings, with many new growing points, tended to tipburn most severely on the lower branches, and to die progressively upwards from the lower portions of the tree.

Tables 2 and 3 show the percentages of test trees with different damage ratings at three- and five-month intervals following the start of the tests. Among trees receiving the same concentrations of salt, damage and symptoms showed some variations in development.

	Salt Concentrations Applied (ppm)	Damage Ratings (Percent of Trees)			
		None	Light	Moderate	Severe
3 Months	0	100	0	0	0
	700	13	87	0	0
	2800	7	80	13	0
	5600	0	17	40	43
5 Months	0	100	0	0	0
	700	64	33	3	0
	2800	0	23	13	64
	5600	0	0	3	97

TABLE 2. The percentages of greenhouse-grown incense-cedars exhibiting different damage ratings at three months and at five months after the start of treatments with varying concentrations of salt.

	Salt Concentrations Applied (ppm)	Damage Ratings (Percent of Trees)			
		None	Light	Moderate	Severe
3 Months	0	100	0	0	0
	700	100	0	0	0
	2800	87	13	0	0
	5600	60	30	7	3
5 Months	0	100	0	0	0
	700	43	37	13	7
	2800	7	13	10	70
	5600	0	3	4	93

TABLE 3. The percentages of greenhouse-grown ponderosa pines exhibiting different damage ratings at three months and at five months after the start of treatments with varying concentrations of salt.

Table 4 shows the percentages of all laboratory-tested trees judged to be dead at the end of the fifth month after the start of salt treatments.

Salt Concentrations (ppm)	Dead Incense-cedar (Percent)	Dead Ponderosa Pine (Percent)
0	0	0
700	0	0
2800	10	44
5600	73	95

TABLE 4. The percentages of greenhouse-grown conifers which died after five months of treatments with varying concentrations of salt.

The concentrations of sodium and chloride in the foliage of different conifer species were greater in the seedlings used in the greenhouse studies than in the trees sampled in the field (Table 5).

Salt Concentrations (ppm)	PERCENT DRY WEIGHT			
	Ponderosa Pine		Incense-Cedar	
	Sodium	Chloride	Sodium	Chloride
0	0.02	0.17	0.12	0.09
700	0.34	1.68	0.04	0.68
2800	1.74	3.42	0.87	2.49
5600	1.38	3.28	1.42	3.91

TABLE 5. The percent dry weight of sodium and chloride in the foliage of greenhouse-grown conifers after five months of treatments with varying concentrations of salt.

These differences may be attributed to several causes: differences in the physiological conditions of the field trees; variations in the ages of the trees or in the environments in which they were growing; inherent genetic differences in the individuals sampled. In addition, the concentrations of salt used in the greenhouse studies may have been greater than those to which field trees were exposed. However, the results of the greenhouse studies were the same as those in the field in that increased sodium and chloride concentrations were correlated with increased symptoms and damage.

CONCLUSIONS

The mean concentrations of sodium and chloride in the foliage of damaged and dead conifers growing within 50 feet of deiced highways in the Basin were several times greater than the mean concentrations found in the foliage of conifers not exposed to salt.

In the greenhouse tests foliage with high levels of sodium and chloride exhibited symptoms identical to those seen on trees in the field — increasingly severe tipburn of new foliage, needle banding on pine, and eventual death of the trees. Therefore, it was concluded that salt is a major cause of damage to conifers growing within 50 feet of deiced highways in the Lake Tahoe Basin.

Estimates indicate that approximately 3000 trees died or were damaged at 321 sites in the Basin during 1973. If salting continues at the current level, not only will trees continue to be damaged and killed, but a substantial proportion of the conifer vegetation within 50 feet of treated highways will be eliminated, and damage to associated vegetation will increase. Increased damage to conifers and to associated vegetation will probably occur at distances greater than 50 feet in certain locations as salt washes into and accumulates in these soils.

RECOMMENDATIONS

The magnitude of the environmental impact caused by highway deicing salt is only partially expressed by the effects on existing vegetation. Studies in the Eastern United States and in Europe have shown that sodium chloride used as a deicing salt over an extended period of time may bring about changes in soil properties, including increased salinity, nutrient imbalance, and reduced flocculation. These salts tend also to alter roadside vegetative patterns and to reduce water quality in streams and wells close to roads upon which salt has been applied (Hanes, et al, 1970; Westing, 1969).

Therefore, it is recommended that studies be conducted on the use of highway deicing salt in the Lake Tahoe Basin. These studies should examine the effects of highway deicing salts on soil properties, the accumulation of salts in the soil, the contribution of these salts to soil erosion, and their effects on water quality and vegetation associated with deiced highways in the Tahoe Basin.

Studies should be initiated also on methods to reduce salt damage by testing different salt and abrasive mixtures, diverting or directing road surface runoff, and planting salt-tolerant vegetation to enhance highway rights-of-way when and if these salts must be used.

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